Choosing appropriate upscaling and downscaling methods for environmental research

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Abstract A decision support instrument is presented that allows the users of models and data for environmental studies to: (a) to identify the temporal and spatial scales involved in the research project, and (b) to identify the most appropriate upscaling and downscaling methods in the given context. The instrument is applied to an operational research chain consisting of several models and independent data sources. Conclusions are: (a) both temporal and spatial scales strongly differ between the models in the research chain, (b) some of these differences are avoidable, (c) though upscaling and downscaling methods are partially integrated in the research chain, some of these methods are still rather primitive. Improvements are possible but may involve extension of the research chain with an upscaling algorithm applied to model outputs.

Key words decision support system; downscaling; environmental models; research chains; upscaling

INTRODUCTION

Environmental studies typically involve the combination of dynamic models with data sources at various spatial and temporal scales. However, the scale of the model output is rarely in tune with the scale at which decision makers require answers or implement environmental measures. Consequently, the question has been raised as to how to obtain results at the appropriate scale. Models, usually developed at the scale of a research project, have to be applied to larger areas (extrapolation), with incomplete data coverage (interpolation) and to different supports (upscaling and downscaling) to facilitate studies for decision makers (Fig. 1). Here, we refer to Bierkens et al. (2000) for an overview of the various problems involved, and limit ourselves to a brief description of two upscaling and downscaling methods. We do this by applying a decision support system (DSS), the details of which can be found in the volume by Bierkens et al. (2000, chapter 4). This DSS advises the practitioner as to which upscaling or downscaling method (out of 23 identified methods) to use in his specific context. Throughout this text, we will use the terms upscaling, downscaling, scale and support. These are defined briefly as follows:

Support (scale) = the largest time interval [T], area [L^2] or volume [L^3] for which the property of interest is considered homogeneous (also called “grain”). For these
time intervals, areas or volumes, we only know the average value of the property considered and not its variation within.

**Upscaling** = increasing the support of the research area.

**Downscaling** = decreasing the support of the research area.

**ANALYSIS OF SCALE DISCREPANCIES IN A RESEARCH CHAIN**

From a practical viewpoint, the first question to be asked is, whether upscaling or downscaling should be part of the study at all. This question can be answered only if one is fully aware of the scales involved in the research chain (defined as the route of data from sampling, through models to the target property, where possible changes of scale occur). Within the DSS, the first step is to identify the following:

(a) What is the target property of the research project, and at what temporal and spatial support size do we want to know this target property?
Choosing appropriate upscaling and downscaling methods for environmental research

407

Choosing appropriate upscaling and downscaling methods for environmental research

407

(b) What model(s) is(are) necessary to obtain this target property, and for what temporal and spatial support size has it been developed and tested?

(c) Which input variables and parameters enter the model(s), and what is their temporal and spatial support size?

(d) How are the models and the data objects linked in sequence?

The above questions were answered (for spatial scales) for a model chain known as STONE (Beusen et al., 1998), which calculates N and P losses to ground and surface water as caused by agricultural inputs (Fig. 2, left). In the figure, three models are mentioned: (a) CLEAN, a model calculating the production, storage, spatial distribution and application of animal manure and fertilizer at national extent and with 31 regions as the basic scale level; (b) CLEAN2, the same model but with the county scale as the basic scale level; (c) ANIMO, a model that calculates N and P losses from fertilized agricultural fields.

Figure 2 shows that the spatial scales within the model chain differ tremendously. Part of these scale differences is unavoidable, since some basic data are available only at the plot scale (m²). Some scale differences however seem redundant (Fig. 2, mark 1); it seems rather useless to first upscale county scale manure production data to the regional scale and thereafter downscale these data to the field scale at which ANIMO operates. This issue has been identified and will be dealt with effectively by the incorporation of CLEAN2 into the STONE model chain (Fig. 2, right).

UPSCALING

One upscaling step in the research chain is that from the m²-scale of soil physical and soil chemical data that enter the 0.01 km² (field-) scale ANIMO model, after which the ANIMO output is again upscaled to the target (km²) scale (Fig. 2, mark 3). We analysed this step with the DSS and compared the advised upscaling method with the upscaling method actually applied. The advised upscaling method follows from the
answers (A, italics) to a sequence of questions (Q) summarized below. It should be noted that this sequence is typical for this case; each answer invokes a succeeding question.

Q1 Is there a model involved in the upscaling step? A1: Yes (ANIMO)
Q2 Is the model linear in (all) its input variables and parameters? A2: No.
Q3 Can the model be easily applied in many locations or timesteps? A3: No, both runtime and parameterization problems (data crisis) prevent application at many locations.
Q4 Would the model have the same form at the two scales involved? A4: Probably not. Some processes would have been modelled differently at the more detailed scale than at the target scale.
Q5 Can the large scale model be analytically derived from the small scale model? A5: No. ANIMO is a complex model, and it is virtually impossible to obtain temporal or spatial averages of all model equations while maintaining the model structure.

From answers 1 to 5, the conclusion is drawn that model simplification is probably the most correct way to obtain a model that produces output at the large scale using upcaled inputs from the detailed scale. The last question is meant to choose between two ways to simplify a model:

Q6 Is it possible to postulate a lumped conceptual model at the large scale? A6: Given the state of knowledge, it should be possible. If not, the construction of a metamodel is an alternative.

In summary, the DSS advises construction of a metamodel or a simplified model from ANIMO, which can be fed with upcaled data. Currently however, the model is applied as-is and so-called “representative” model inputs are generated for spatial units delineated by soil type and land use maps. The main reason for this is that as many processes as possible should be included in the model to allow for the analysis of a large band width of scenarios. Given this reasoning, the advice would be one of the two following options:

(a) to investigate whether the generated representative model inputs do truly produce representative model output. A method for this would be application of the model to a large number of field-scale plots and subsequent comparison of the upscaled results to that from a single calculation with representative inputs. This analysis could be repeated for different typical areas (e.g. soil regions).
(b) to run the ANIMO model for many field-scale plots with local data, and subsequently upscale the model outputs to the target scale. This would imply the addition of a postprocessor in the model chain that upscales ANIMO output to the desired target scale. Also, the input to ANIMO would again need to be generated at the field scale for a large number of locations.

DOWNSCALING

One downscaling step in the research chain is that from manure distribution at the scale of the administrative region (10 000 km²) or county scale (100 km²) towards the field scale of ANIMO (Fig. 2, mark 2). As in the previous case, the advised downscaling method follows from the answers (A, italics) to a sequence of questions
Choosing appropriate upscaling and downscaling methods for environmental research

(Q) summarized below.

Q1 Is there auxiliary information that can be used to explain some of the unknown temporal or spatial variation of the property at the detailed scale? 
A1: Yes, detailed soil and land use maps are available.

Q2 Is the average value of the property at the large scale exactly known? 
A2: Yes, manure figures are based on a yearly sample (or on a scenario).

Q3 Is the temporal or spatial variation of the property at the detailed scale described with a single deterministic function? 
A3: Yes, the land use and soil type are considered to be the major variables governing the manure distribution within the administrative (or county) area.

Based on these answers, the DSS advises a downscaling method called “downscaling with deterministic functions using auxiliary data”. In practice, this is what is done as well. Soil/crop combinations have characteristic fractions of total manure applied to them, where the fractions sum up to 1. Two factors that deserve attention here are (a) that the soil/crop combinations occupy equal areas in both the ANIMO and the CLEAN model, and (b) it is possible that the “characteristic fractions” vary by administrative (or county) spatial unit. The first condition accounts for the preservation of mass while downscaling. The second condition allows for maximum regional detail and could be inventoried in the same yearly sample that is taken to assess the manure volumes.

REFERENCES
